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Comparison of Mechanical & Corrosion behavior of Aluminum Alloys Weldments

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Abstract: In the ship manufacturing industries, welding is used to join the different aluminum parts of the ship structure, these weldments are generally remaining dip in saline water of sea or remain in salt foggy atmosphere, which gets eroded early when comes in contact with salt-water solution. In the proposed research work, after joining 5086-H116 aluminum alloy by friction stir welding, and TIG welding, the mechanical examination and comparison was done. The main objective of the present research work was to compare corrosion behaviour of FSW and TIG weldments of AA5086-H116 using ASTM G66 and ASTM G67 corrosion test standards.
Keywords: AA5086-H116; Corrosion behavior; ASTM G66; ASTM G67.

I. INTRODUCTION

Metallic corrosion takes place in wet environments when the chemical or electrochemical reaction between a metal and the surrounding environment results in the oxidation of the metal. For corrosion to occur, electrons are produced by the anodic oxidation of the metal must be consumed in a cathodic reaction. These two processes can take place on different parts of a metal structure providing that there is a conducting path for the electrons between the two, and a continuous electrolyte path for ion transport. Aluminum is highly reactive, with a negative standard electrode potential of - 1660mV, and is therefore unstable in the presence of water. However, aluminum reacts quickly with the oxygen in air or water to form a protective oxide film (alumina, Al□O□) that is stable in pH range 4-9 and prevents corrosion of the metal. There are three main types of localized corrosion that affect aluminum in aqueous environments: pitting corrosion, intergranular corrosion, exfoliation corrosion, whereby the mode of corrosion that takes place depends strongly on the alloy, its processing history and its environmental conditions. Aluminum alloys of 5xxx series and their welded joints show good resistance to corrosion in sea water. 5086-H116 is one of such an excellent marine environment corrosion resistant aluminum alloy, most commonly used in North America[1]. It is a marine grade alloy used for its excellent corrosion resistant properties.

In the ship manufacturing industries, TIG welding is used to join the different aluminum parts of the ship structure, these weldments are generally remaining dip in saline water of sea or remain in salt foggy atmosphere, which gets eroded early when comes in contact with salt-water solution due to the HAZ area of TIG weldments which is generally large and causes initiation of localized corrosion easily [2]. The problem can be solved if the welding process is changed to friction stir welding that produces comparatively very less HAZ area, and also if we compare the cost of welding process, it was observed that the cost of friction stir welding is 15-20 times less than the cost of TIG welding [3].

Squillace et al., [4] compared two different welding processes one is conventional tungsten inert gas (TIG) process and second is friction stir welding (FSW). A micro-hardness measurement allows pointing out a general decay of mechanical properties of TIG joints, mainly due to high temperatures experienced by material. In FSW joint, instead, lower temperatures involved in process and severe plastic deformations induced by tool motion allow rising of a complex situation: by a general point of view a slight decay of mechanical properties is recorded in nugget zone, flow arm and thermo-mechanically altered zone (TMAZ), while in heat-affected zone (HAZ), due to starting heat treatment of alloy under investigation, a light improvement of such properties is appreciated. In flow arm and in nugget zone, however, a light recovery of hardness, w.r.t. TMAZ zone, is recorded, due to the re-crystallisation of a very fine grain structure.

Zhao et al., [5] welded Al–Mg–Sc alloy plates by FSW and TIG welding. The effect of welding processes on mechanical and metallurgical properties of welded joints was analyzed. The results shown that the mechanical properties of FSW welded joint are much better than those of TIG welded joint. Moreover, tensile strength and yield strength of FSW joint are 19% and 31% higher than those of TIG joint, respectively. Due to the low welding temperature during FSW process and the excellent thermal stability of Al_3 (Sc, Zr) particles, the cold working microstructures can be well preserved.

Anjaneya Prasad, and Prasanna P. [6] experimented AA6061 joints welded by Metal Inert Gas (MIG) and Friction Stir Welding (FSW). The FSW was carried out by 3 axis computer numerical controlled milling machine. semiautomatic welding machine MIG 350 carried out the MIG welding with the welding speed of 110mm per min. FSW showed 10-100 times smaller grains than the MIG welding in the microstructure of the weld joints. MIG welding produced the less tensile strength than FSW. The amount of heat input affected the weld material hardness and the width of hardness was determined by shoulder diameter and heat input. The FSW reduced production cost, pre operations and increased the weld quality.

Grilli et al. [7] focussed on the on the role of intermetallics in pitting corrosion of AA 2219 alloy. Second phase particles were characterized by AES, SAM and EDX. Their behaviour in a solution of NaCl was investigated as a function of exposure time. The results confirmed the cathodic nature of the intermetallics with respect to the aluminium matrix. Corrosion products rich in aluminium and oxygen were found to progressively accumulate around the particles and iron was dissolved from the intermetallic, followed by back deposition. Copper and manganese did not show any major activity.

Proton et al.[8] investigated the corrosion behaviour of the nugget of a Friction Stir Welding joint employing a 2050 Al–Cu–Li alloy. The results showed that the nugget was susceptible to both intergranular and pitting corrosion. Such corrosion behaviour was related to microstructural heterogeneities observed on a microscopic scale.

This experimental work was carried out for mechanical and corrosion behaviour comparison of FSW and TIG weldments of AA5086-H116 aluminium alloy.

II. EXPERIMENTATION

The material plate was cut into the specified dimensions of 150 mm long and 100 mm wide for friction stir welding and into dimensions of 150 mm long and 50 mm wide for TIG welding.

The chemical composition of the base material and mechanical properties are presented in Table 1 and Table 2 respectively.

Table 1 Chemical Composition of AA5086-H116 Aluminum Alloy

Base material	Mg	Zn	Mn	Fe	Cu	Si	Al
AA5083-H116	4.49	0.06	0.49	0.38	0.06	0.34	Balance

Table 2 Mechanical Properties of AA5086-H116 Aluminum Alloy

Material/Property	Tensile Strength	Hardness	Impact Strength
AA5083-H116	290 Mpa	89	18

The friction stir weldment was prepared on simple vertical milling machine installed at CTR Ludhiana, Punjab India. The friction stir welding was performed by using the process parameters given in table 3. These values of process parameters were selected after conducting trial experiments.

Table 3 FSW Welding parameters used

FSW process parameters	Value
Tool rotational speed (RPM)	800
Welding speed (mm/min.)	50
Tool pin profile	Taper cylindrical

The PC-TIG weld joint was prepared by the help of Panasonic 300WP5 PC-TIG welding set installed at Bahara University, Shimla. Peak current, base current and gas flow rate critical welding variables were selected for carrying out the experiment work. The TIG welding was performed by using the process parameters given in table 4. These values of process parameters were selected after conducting trial experiments.

Table 4 TIG Welding parameters used

TIG	Value
Current (amp)	160
Base current (amp)	80
Gas flow rate (L/min.)	10

Test specimens were prepared for tensile testing. The beginning and the end of the weld joint with holes were sheared. Distribution planning of the specimens for tensile, impact testing and corrosion testing on the weld joints is shown in Figure 1. From each joint, one tensile specimen, one impact test specimen, one corrosion testing specimen ASTM G-66 and one corrosion specimen ASTM G67 test were extracted.

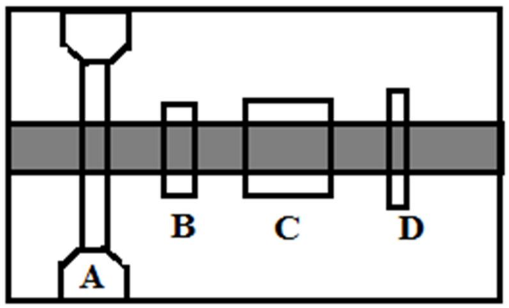

Figure 1 Testing Samples Plan

(A: Tensile test specimen, B: Impact test specimen, C: ASTM G67 corrosion test specimen, D: ASTM G66 corrosion test specimen)

III. RESULTS AND DISCUSSION

A. *Weld appearance*

The weld bead appearance of FSW and TIG weldments are shown in fig 2(a) and fig. 2(b). It is clearly shown that the weld bead appearance of FSW weld joint is far better than in case of TIG weld joint.

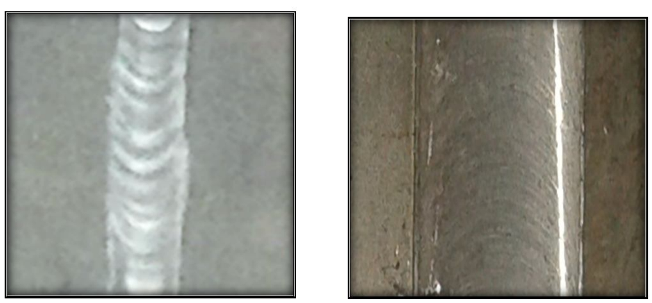

Figure 2 (a) TIG weld (b) FSW

B. *Comparison Of Ultimate Tensile Strength*

The ultimate tensile strength of FSW and TIG welded joints is shown in Figure 3. The tensile strength of base material was 310 MPa. The tensile strength achieved in TIG welded joint was 204 MPa. This shows 35% reduction in tensile strength of TIG welded joint. FSW joints showed the tensile strength of 271 MPa, this shows 13% reduction in tensile strength. However, in both cases, the tensile strength of FSW weld joints and TIG weld joints was lower than that of the base metal, but tensile strength of friction stir weld joints was 22% higher than TIG welded joints. This suggests that friction stir welded joints were stronger than TIG welded joints. The comparative investigation shows that the TIG welding process strongly influences the tensile strength which decreases 35% in comparison to that of the base material. In case of FSW, the tensile strength of the weld decreases 13% in comparison to that of the base material. Thus, the tensile strength of AA5086 was affected by both the welding processes but affect is more in the TIG as compared with FS welded joints.

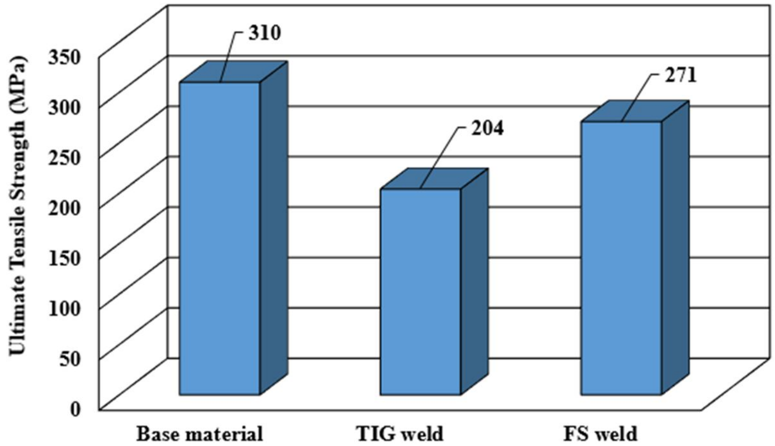

Figure 3 Comparison of ultimate tensile strength

C. Comparison of impact strength

The impact strength of FSW and TIG welded joints is shown in Figure 4. The impact toughness of FSW was greater than TIG joints and base material. The measured value of impact toughness base material was 24 Joules, whereas the welds made by FSW process showed impact toughness value (21 joules) was near about the value for base material. This situation can be explained with the grain refinement of the stirring effect in the FSW process. Impact strength of TIG welded joint was 14 Joules and lower due to larger grain size of the welded joints. The impact toughness of the FSW joint was 48% greater than that of the parent material but impact toughness of TIG weld joints was 40% lesser than that of the base metal.

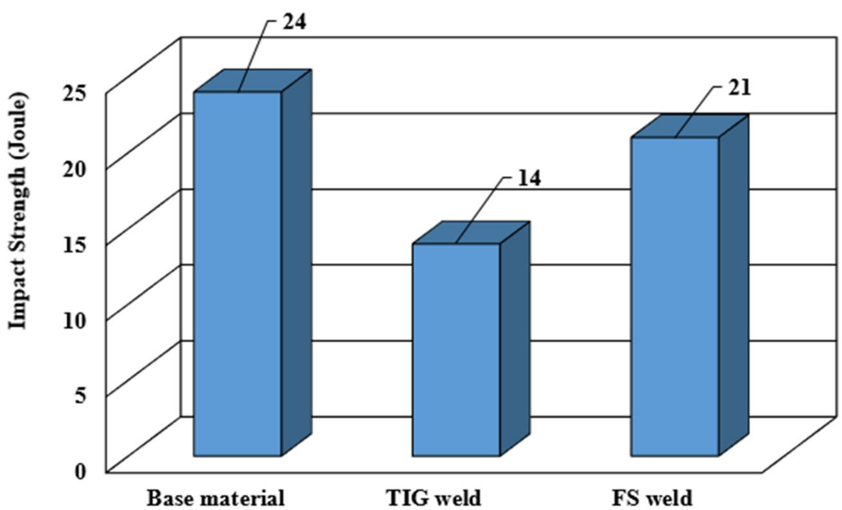

Figure 4 Comparison of impact strength

D. Comparison of hardness

The hardness of base material, FSW and TIG welded joints is shown in Figure 5. The hardness was reduced in the weld region of both the welding processes. the hardness value was measured at the center of the weld zone. The lower value of hardness 85 VHN in TIG weld joint clearly reveals the inferior tensile behavior. The hardness reduction at weld zone at TIG weld joint is 14% as compared to only 2% in case of FSW weld joint (97 VHN).

The grain size of the fusion zone is influenced by the heat input of the welding process. The grains in the fusion zone were found to be grown larger due to the intensive heat and high temperature experienced during TIG welding as compared to fine grains in case of FSW welding.

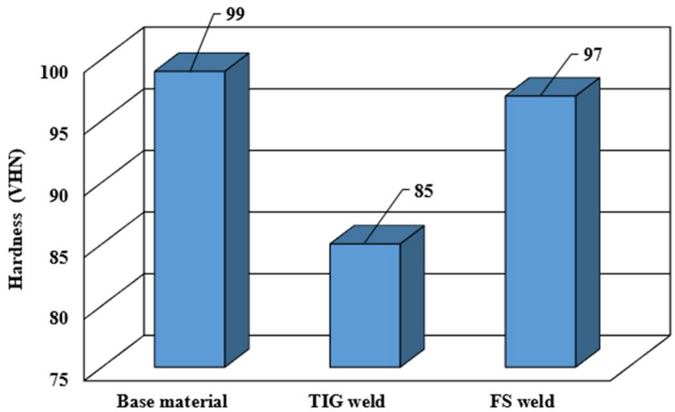

Figure 5 Comparison of hardness

E. ASTM G66 corrosion Test Results

Figure 6 and Figure 7 show surface visual appearance and Scanning Electron Microscopy (SEM) morphology of the corrosion test samples (FS and TIG weld) of the intergranular corrosion tests (ASTM G66). The FS weld joint (Fig. 6) presents a superior resistance to intergranular attack followed by TIG weldments (Fig. 7). In case of FS weld sample, only small extent of etching can be seen as compared to pitting in TIG weld sample.

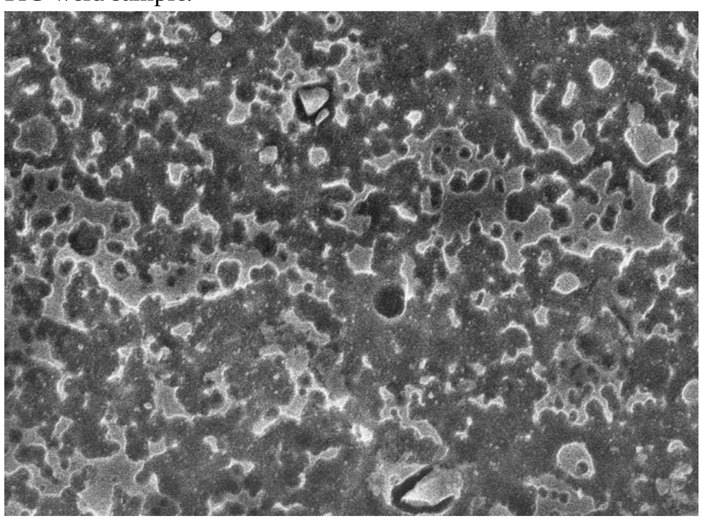

Figure 6 Scanning Electron Microscopy morphology of the ASTM G66 corrosion test of Friction stir weld joint

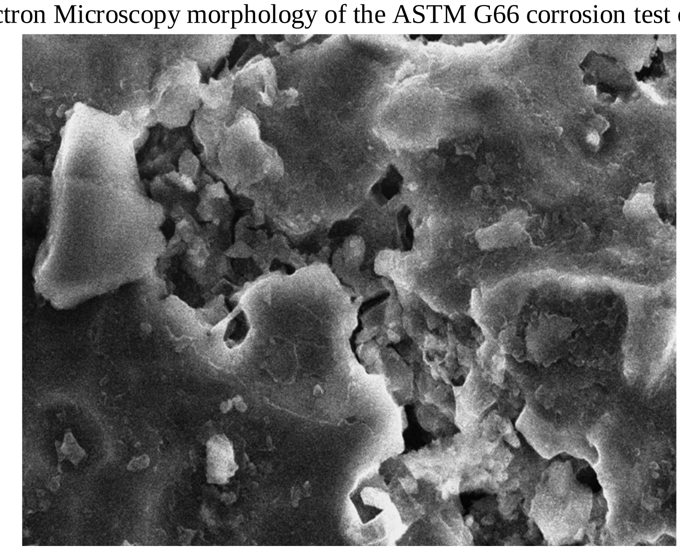

Figure 7 Scanning Electron Microscopy morphology of the ASTM G66 corrosion test of TIG weld joint

F. ASTM G67 corrosion test results

Figure 8 & Figure 9 shows surface visual appearance and Scanning Electron Microscopy (SEM) morphology of the corrosion test samples (FS and TIG weld joints) of the exfoliation corrosion tests (ASTM G67). Figure 8 shows that the FS weld joint presents a superior resistance to exfoliation corrosion than TIG weldments (Fig. 9).

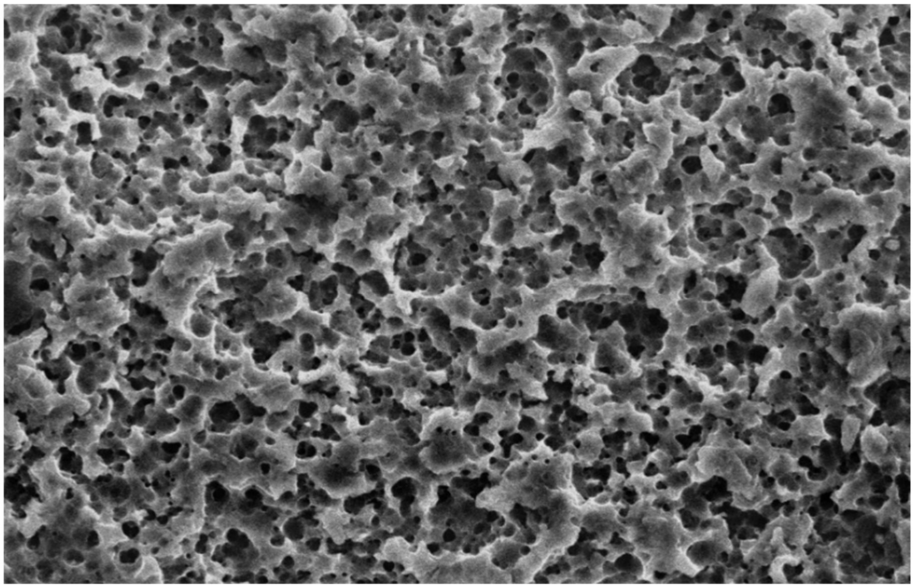

Figure 8 Scanning Electron Microscopy (SEM) morphology of the G-67 corrosion test sample Friction stir weld

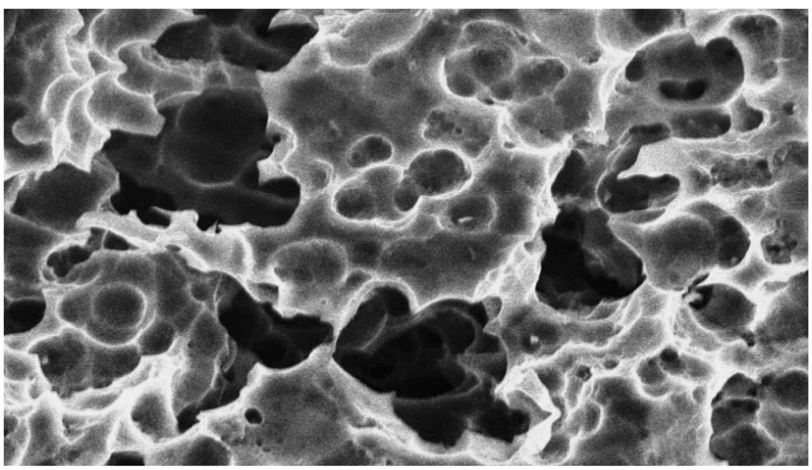

Figure 9 Scanning Electron Microscopy (SEM) morphology of the G-67 corrosion test sample TIG weld

Table 5 shows mass loss value for three samples in the NAMLT test. Dotted lines show the classification of degree of sensitization to intergranular corrosion. According to the standards, the alloy is considered resistant to intergranular corrosion when the mass loss per unit area is less than or equal to 15 mg/cm^2, and if it is greater than or equal to 25 mg/cm^2, then the alloy is considered susceptible to intergranular corrosion. When the mass loss is between 15–25 mg/cm^2 the sensitivity to intergranular corrosion is undetermined. It has been observed that the loss mass in the TIG weld samples (33.36 mg/cm^2) is higher than in the FS welded samples (11.07 mg/cm^2). Thus from the it can be concluded that the friction stir welding did not influence the corrosion behavior as compared to TIG welding.

Table 5 Mass loss value for corroded samples in the NAMLT test

Sample	Weight before	Weight after	Mass loss	Surface area	Mass loss/area
TIG weld	4672.3	4285.1	387.2	11.6	33.36
FSW weld	4454.7	4326.3	128.4	11.6	11.07

IV. CONCLUSION

From the results derived from these experimentations following conclusions have been drawn.

A. The ultimate tensile strength, impact strength, and hardness values of friction stir weld joints were higher than those of TIG weld joints. It was concluded that the friction stir welding performs better in terms of mechanical properties for AA5086-H116 as compared to tungsten inert gas welding.

B. In present work, the susceptibility to intergranular (IGC) and exfoliation corrosion of parent substrate, TIG welded and FSW welded samples of AA5086-H116 alloy at selected working conditions were investigated according to the ASTM G66 and ASTM G67 standards.

C. The parent substrate selected was excellent corrosion resistant material and follows ASTM 928M standards for marine services.

D. From investigations, ASTM G66 test explored that FS weldments have superior resistance to exfoliation resistance, but are prone to pitting corrosion of low intensity, as compared to exfoliation corrosion occurred on TIG weldments.

E. From the ASTM G67 test, it could be concluded that the TIG weldment of the substrate material failed to follow the ASTM 928M standards as mass loss was 33.36 mg/cm^2 attributed to severe β-phase dissolution in nitric acid and had undergone intergranular corrosion. Whereas friction stir weld showed excellent corrosion resistance to intergranular corrosion, where the mass loss was 11.07 mg/cm^2, which is considered as a measure to be insensitive to intergranular corrosion as per ASTM G-67 standards.

F. Thus it can be concluded that friction stir welding process can successfully produce the excellent corrosion resistant joints of AA5086-H116 as compared to tungsten inert gas welding.

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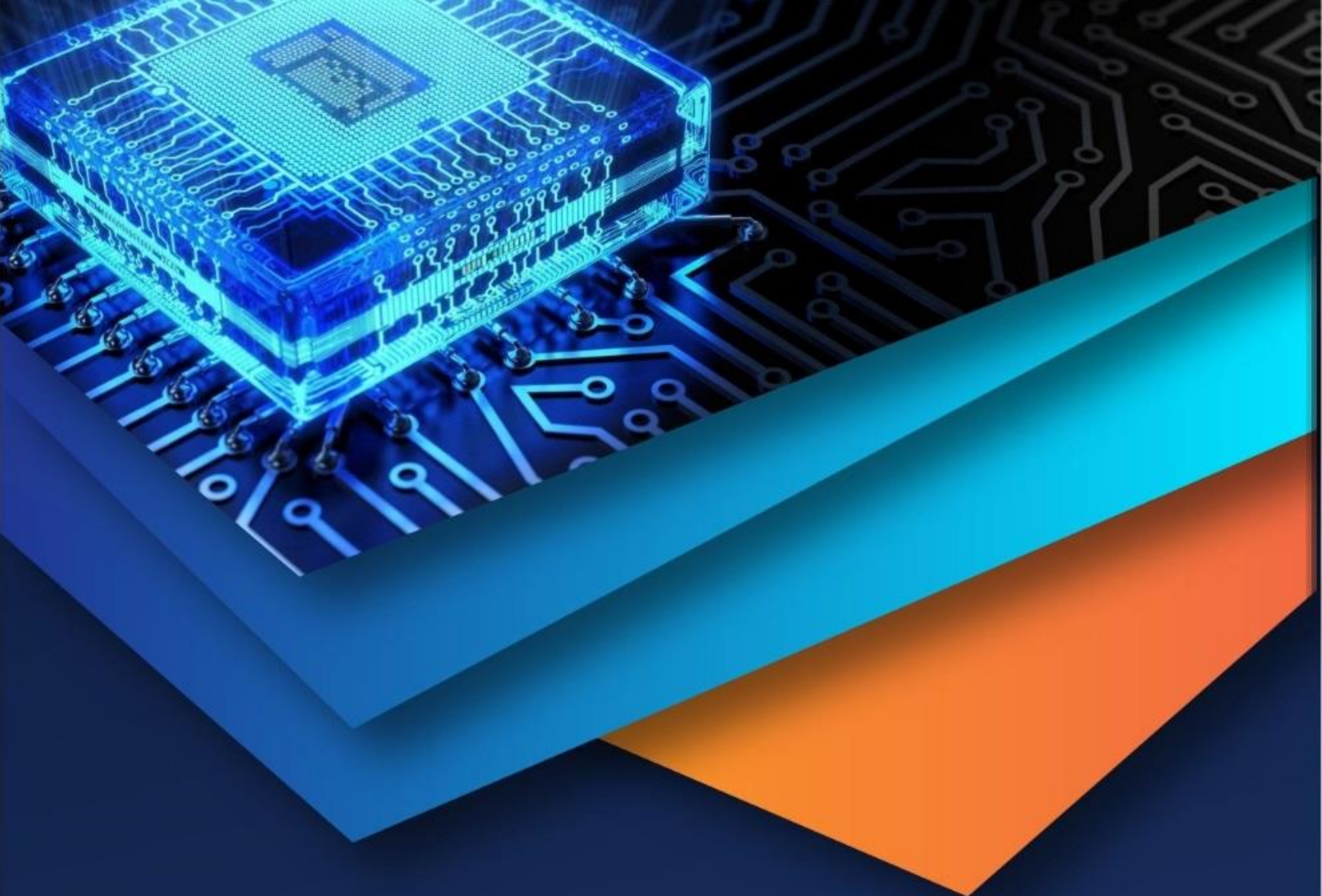

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